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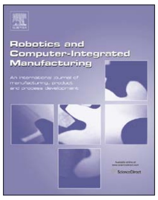

Process planning for 8-axis robotized laser-based direct metal deposition system: A case on building revolved part

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ABSTRACT

Laser-based direct metal deposition (LBDMD) is a promising additive manufacturing technology that is well suited for production of complex metal structures, low-volume manufacturing, and high-value component repair or modification. It finds broad application in the automotive, biomedical, and aerospace industries. The Research Center for Advanced Manufacturing (RCAM) at Southern Methodist University is developing a robot controlled LBDMD system that couples a 6-axis robot arm with an additional 2-axis tilt and rotatory positioning system. The system simplifies the process planning of multiple-directional deposition for complex parts and reduces production time. This paper describes the printing process specific to complex revolved parts. Taking advantage of the coupled 2-axis tilt and rotatory system, a hybrid slicing method is developed to map the overhanging structures of a revolved part to be at a planar base. Consequently, the traditional path planning strategies are applicable to generate the tool-path for the mapped structures. The method is successfully applied to build a propeller.

1. Introduction

Laser-based direct metal deposition (LBDMD) is a promising additive manufacturing technology that builds metal components layer upon layer. The process forms a molten pool on the substrate by using a laser beam and feeding metal powder/wire into the molten pool. The technology is well suited for the production of complex metal structures, low-volume manufacturing, and high-value component repair or modification [1,2]. LBDMD technology finds wide acceptance in various industries including automotive, biomedical, and aerospace. The high spatial resolution of the well-defined laser beam allows the state-of-the-art LBDMD to build near net-shaped components from CAD files. For this purpose, challenges were identified relating to process planning, process state sensing and control [3], microstructure optimization [4], expansion of build volume, reduction of production time, and production of functional materials [5]. The Research Center for Advanced Manufacturing (RCAM) in Southern Methodist University is developing a robot controlled 8-axis system targeting solution and improvements to meet those challenges. This paper describes the development of process planning of building complex parts based on the 8-axis robotized laser-based direct metal deposition system.

In most LBDMD techniques, the fabrication of complex parts that have overhanging structures relies on support structures. Once the parts are constructed, machining or chemical treatment removes the support structures. The process is time-consuming, inefficient, and involves human intervention at multiple steps. Multiple-directional deposition [6–9] eliminates the requirement of the support structures by suitably orienting the part during the deposition process. This reorientation eliminates or minimizes the need for support during the deposition process. P. Singh et al. [6] brought forth issues associated with the use of multi-axis robot arm and established a task framework for the multi-direction slicing of a CAD model. Zhang J. et al. [8] developed a multiple-directional slicing algorithm for increasing the build capability of a 5-axis LBDMD system based on the two techniques: transition wall and surface tension. R. Dwivedi et al. [7,9] developed an expert system for the multi-directional fabrication based on a manipulator that consisted of a 6-axis robot and a 5-axis CNC machining center. Industries also made efforts to develop LBDMD systems based on machining centers including LASERTEC 65 from DMG MORI [10] and INTEGREX i-400AM from Mazak [11]. These efforts show their ability to build complex parts. As of yet, no report exists of the construction of a 6+2-axis robotized LBDMD system that couples a 6-axis robot arm with an additional 2-axis tilt and rotatory positioning system. The synchronized motions of a robot and positioning system have the potential to simplify the process

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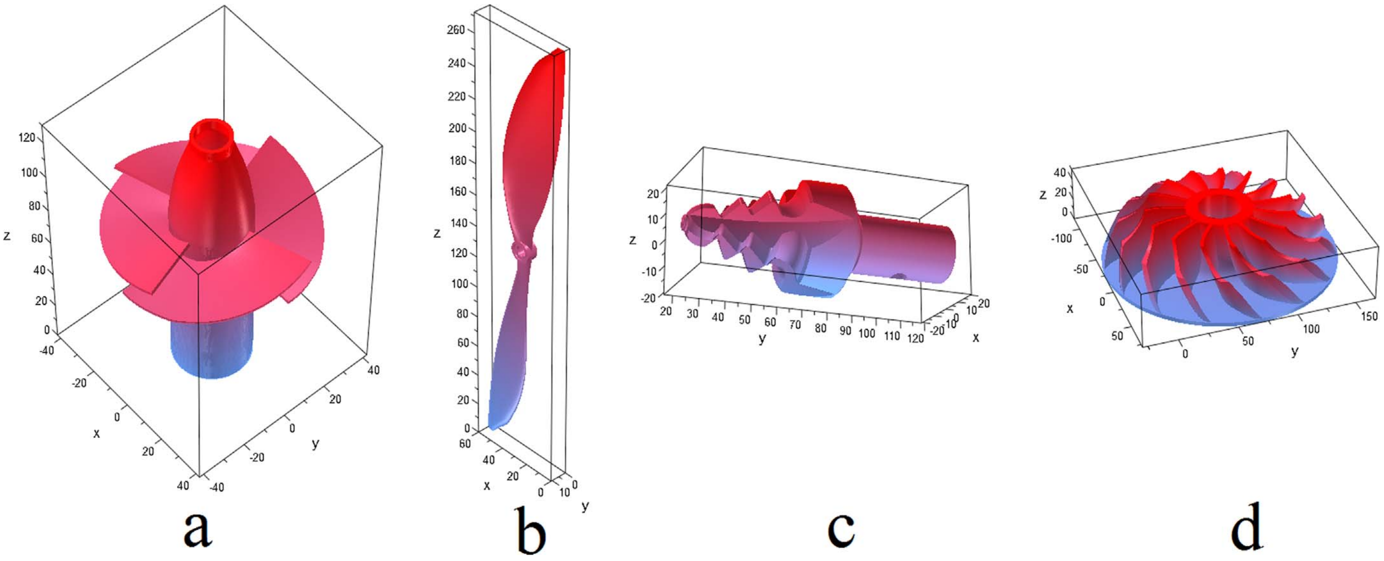

Fig. 1. Revolved part: (a) propeller a, (b) blade, (c) cutter head, (d) propeller .

planning and reduce production time. For example in the existing systems during deposition, the rotation of the worktable conducts the reorientation of the built part [7,10,11]. That reorientation introduces an offset of the laser head with respect to the built part in the X, Y, Z directions. The laser head needs to retrieve the position of the built part each time before depositing the next layer. With the coupled 2-axis positioning system, the laser head orientates and moves with respect to the built part that is fixed on the positioning system. When the built part moves, the laser head continuously follows the built part. That enables the reorientation of the built part by the combination of the reorientation of the laser head and the tilt/rotation of the positioning system without an offset. This simplifies the process planning and saves a lot of production time. Utilizing this characteristic of the 8-axis LBDMD system, this paper describes the printing process specific to the complex revolved part. The revolved part consists of a core-volume and several overhanging structures with complex geometries. Characteristic to the core-volume is a geometry obtained by revolving planar section about a central axis. Most of the core-volumes such as for the blade in Fig. 1b and propeller in Fig. 1d have a rectangular plane of rotation, while for some others such as the propeller in Fig. 1a and the cutter head in Fig. 1c, the plane of rotation varies in axial and radial directions respectively. The revolved parts are widely used in aerospace and shipyard. The traditional manufacture of this kind of part is not desirable due to the interference of tool with the part, plastic deformation during milling, long production time, and large material subtraction. Taking advantage of the coupled 2-axis system, this paper proposes a hybrid slicing method that maps the overhanging structures of a revolved part at a planar base. Consequently, the traditional path planning strategies are applied to generate the toolpath for the mapped structures. With the help of the coupled positioning system, the overhanging structures are built at a planar base rather than radially distributed around the core-volume.

2. Setup of LBDMD system

The schematic and the photo of the LBDMD system are shown in Fig. 2a and b respectively. A 4 kW fiber laser with a wavelength of 1070 nm and a laser head are mounted on a KUKA 6-axis robot arm to perform the direct metal deposition process. For the process planning, the system is represented by the BASE kinematic system (additional 2-axis tilt and rotatory positioning system) that is spatially coupled with the 6-axis robot. As shown in Fig. 2c, six Cartesian coordinate systems are defined in the system: WORLD, ROBROOT, ROOT, FLANGE, OFFSET, and TOOL. The WORLD coordinate system is fixed. The Coordinate systems for the Robot (ROBROOT) and for Tilt and Rotary table (ROOT) are defined in the context of the WORLD coordinate system. The ROBROOT

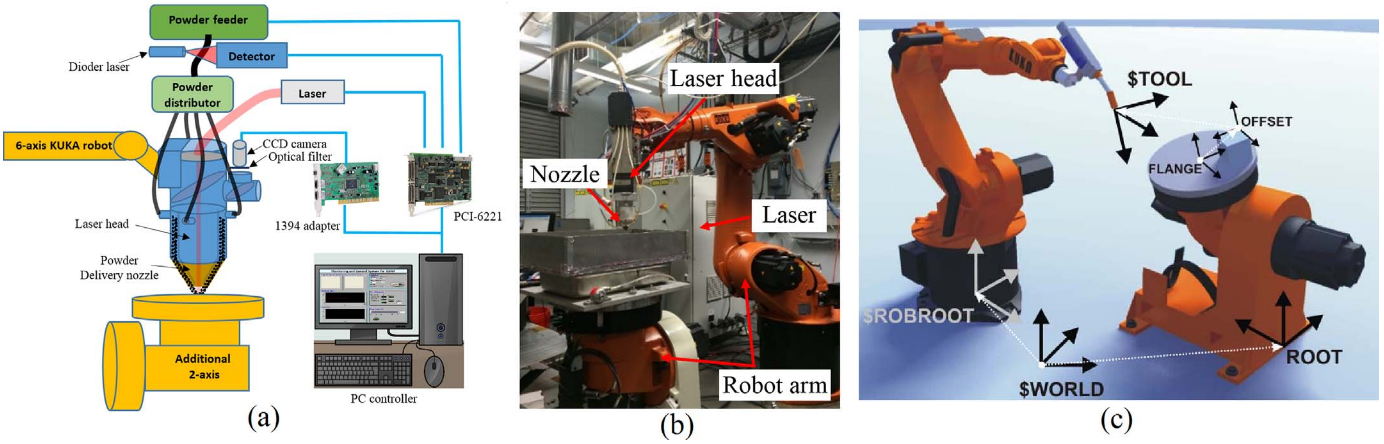

Fig. 2. Setup of the LBDMD system. (a) schematic, (b) photo, (c) coordinate systems.